HIGH PERFORMANCE MISFET USING HIGH-MOBILITY SUBSTRATE AND ALUMINUM OXIDE GATE INSULATOR

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Abstract

Diamond is expected as a next generation semiconductor for high power and high frequency applications. In this study, diamond MISFETs have been fabricated on H-terminated B-doped diamond to increase the maximum drain current and transconductance. For 1-µm-gate-length MISFETs, the high I_{Dmax} of more than 230 mA/mm and the high g_m of 65 mS/mm have been obtained. Concerned influences on drainconductance and buffer leakage are not observed. Diamond MISFETs using naturally oxidized aluminum as the gate insulator have been also demonstrated. The excellent subthreshold characteristics of 95mV/dec and the low gate leakage current less than 1E-6A/mm^2 are obtained.

1. INTRODUCTION

Wide bandgap semiconductor diamond has excellent material properties such as highest thermal conductivity (22 W/cmK), high break down field (10^7 V/cm) and low dielectric constant (5.5). Figures of merit (FOM) of diamond are extremely high. For example, Johnson's FOM of diamond is much higher than that of other materials even in wide-gap materials; that is 100, 2.6, 2.5 times of Si, SiC and GaN, respectively. Therefore diamond is expected to realize high-frequency and high-power device.

The surfaces of diamond films deposited by plasma- assisted chemical vapor deposition (PACVD) are terminated by hydrogen. The hydrogen-terminated (H-terminated) surface exhibits p-type. This H-terminated surface conductive layer is suitable for the channel of field-effect transistors (FETs) because of the following excellent properties. 1) The sheet density of holes is as high as 10^{13} /cm^2. The carrier density is constant in the temperature range from 150 K to 400 K because of the low carrier activation energy of less than 50 meV. 2) The carriers are confined in a thin subsurface region of less than 10 nm thickness. 3) The H-terminated surface exhibits a low density of surface states (less than 10^{11} /cm^2), which might be due to the termination of surface dangling bonds by the hydrogen atoms.

2. MISFETS ON B-DOPED DIAMOND SUBSTRATES

Good DC and RF performances of diamond FETs on H-terminated diamond which has the resistivity of 10kΩ/sq and mobility of 100 cm^2/V· sec have been reported. Up to now, the drain current over 200mA/mm [1] and the cut-off frequency over 20GHz [1,2] have been obtained. However, the carrier density or mobility of H-terminated diamond films are difficult to control. In addition, due to the shallow channel of the surface conductive layer, the maximum current density of the FETs reaches MA/cm^2, this large current density decrease reliability of the diamond FETs. In this study, we developed the diamond MISFETs on H-terminated B-doped films to improve the transconductance and the maximum drain current by means of increase of the channel mobility and the thickness of the current flow.

Diamond MISFETs using calcium fluoride (CaF_2) as a gate insulator are fabricated on H-terminated lightly B-doped diamond films. The carrier concentration, film thickness and Hall mobility of the film are 5×10^{14} cm^{-3}, 200nm, 379 cm^2/V· sec, respectively. The DC output characteristics of a 1µm gate length MISFET is shown in Figure 1. The maximum measured drain current is I_{Dmax} = 230mA/mm at V_{GS} = -3V. The maximum g_m is 65mS/mm. Those values are relatively high for 1µm gate length MISFETs. For this device because the aspect ratio of the gate length to B-doped layer thickness is 5, which value is enough to suppress the short channel effect for GaAs devices, serious buffer leakage doesn't occur. In saturation region, high g_m/g_d ratio of 130 is obtained due to the low drainconductance of 0.5mS/mm. The cut-off frequency and the maximum frequency of oscillation of the 1µm gate length MISFET are, respectively 4GHz and 10GHz, respectively.

3. MISFETS USING NATURALLY OXIDIZED ALUMINIUM

For high power transistor application, reduction of the gate leakage current is important to improve efficiency, self-heating and reliability. High-k and stable gate insulator is needed to reduce the gate leakage current. Recently, new gate insulator materials such as aluminum or hafnium oxides are well researched for next generation CMOS application. However, these oxide insulators have generally high melting point (>1800°C) and are deposited by sputter coater or chemical vapor deposition. To prevent surface damage such as oxidation or defects, which make the resistivity of H-terminated surface high, these processes cannot be adapted diamond MISFET fabrication process. The natural oxidized aluminum is one of the promising gate insulator materials to meet the problems.

Evaporated aluminum on H-terminated undoped diamond film is oxidized in oxygen environment at room temperature. Using aluminum as a gate electrode, a 0.5µm gate length diamond FETs are fabricated. Figure 2 shows subthreshold characteristics at V_{DS} = -50mV. The minimum subthreshold factor is 95mV/dec, which value is one of the best for sub-micron gate diamond MISFETs at present. The gate leakage current is as low as 1E-6A/mm^2 without dependence on polarity of gate swings, indicating the naturally oxidized gate insulator suppress the gate current.

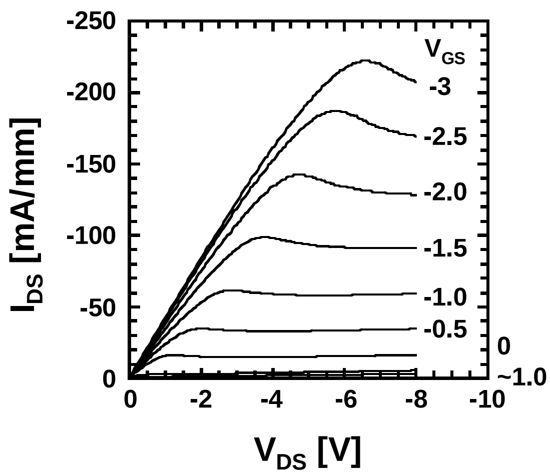

Figure 1. DC output characteristic of a 1µm gate length MISFET with 50nm CaF_2 gate insulator.

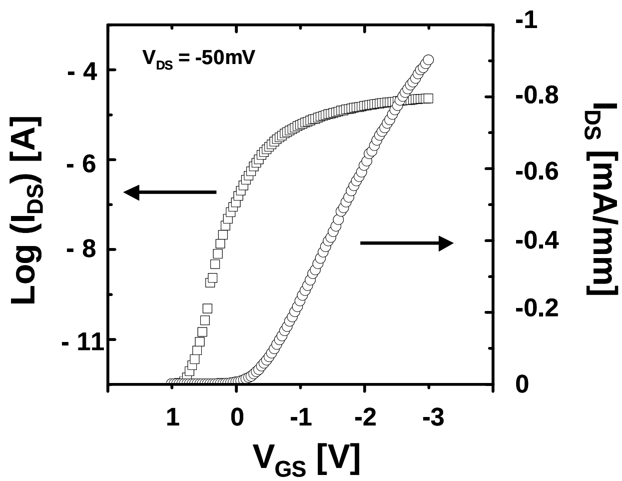

Figure 2. Subthreshold characteristics of a 0.3µm gate length MISFET with 8nm naturally oxidized Al as gate insulator.

REFERENCES

1. M. Kubovic, M. Kasu, et al, “Microwave Performance Evaluation of Diamond Surface Channel FETs” *Diamond and Related Materials*, Vol. 13, No. 4-8, pages 755-760(2004).
2. H. Umezawa, S. Miyamoto, et al, “RF Performance of Diamond Surface-Channel Field-Effect Transistors” *IEICE*, Vol. E86-C, No. 10, pages 1949(2003).